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Primary insomnia patients' performances during simulated car following and urban driving in the afternoon

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1. Introduction

Among sleep disorders, insomnia is one of the most prevalent health concern in the general population and is defined as complaints of non-restorative and/or insufficient sleep and is associated with daytime fatigue and cognitive difficulties (Fortier-Brochu et al., 2012; Perlis et al., 2014). Higher risks of road traffic accidents have been described with sleep disorders in general (Léger and Ement, 2015; Stutts et al., 2003), and estimated to 2.5- to 3-fold higher risk of serious road accidents for insomnia suffering persons compared to good sleepers (Léger et al., 2006). These epidemiological findings indicate potential occurrence of driving impairments in insomnia patients.

In order to obtain objective evidence of driving impairment in insomnia patients, two experimental studies have been conducted by assessing driving performances during monotonous driving tasks using Standard Deviation of the Lateral Position (SDLP) as main outcome, however discrepant results were found (Leufkens et al., 2014; Perrier et al., 2014). Whereas Leufkens and colleagues (2014) did not found impaired performance in insomnia patients in comparison to normal sleepers performance, Perrier and colleagues (2014) did. One of the differences that could explain this discrepancy is the simulated (Perrier and colleagues) versus the on-the-road driving task (Leufkens and colleagues) that had in Perrier and colleagues's study facilitated the detection of an impaired driving performance in the insomnia group after 20 minutes of driving. The authors showed that insomnia patients were able to perform as well as good sleepers only for a short period of time, and proposed that the impairment after 20 minutes occurred because of decrease in vigilance.

Perrier and colleagues's results indicate that insomnia patients had difficulties in monotonous and long duration driving tasks; however, it is not established whether other driving situations may be impacted by insomnia, especially those needing more attentional resources than those mainly involved in monotonous driving. Using laboratory tests, such as the Switching Attention Task and the N-Back task to assess respectively switching attention and working memory, Shekleton et al., (2014, 2010) revealed that impairments are more likely to occur with the increase of cognitive demands. Although results from these studies objective insomnia patients' daytime difficulties, they are not representative

of difficulties expressed by patients in situations encountered in everyday life (i.e. driving in urban environment with traffic and critical situations). Therefore, such driving behaviors need to be explored.

Urban driving and car following are part of the driving situations that are the most frequently encountered in everyday life in many countries. Especially, car following ability has been shown to be one aspect of driving and the ability to perform this task is crucial for safe driving (see Saifuzzaman and Zheng, 2014, for review). Few studies have investigated these two driving situations, and particularly urban driving. This later task is of particular interest as spatio-temporal characteristics of real situations leading to traffic accidents (Berthelon et al., 2008) are reproduced in scenarios in a controlled virtual environment. . Both car following and urban driving tests have been found to be sensitive to reveal performances impairments of older drivers (Doroudgar et al., 2017) and after various drugs intake (such as hypnotic treatments, MDMA, alcohol) (Amato et al., 2013; Berthelon et al., 2003; Kuypers et al., 2006; Meskali et al., 2009; Schumacher et al., 2017) both using simulated and on-the-road driving tests; however no previous studies have investigated sleep disorders and particularly insomnia patients' performances under such situations.

The urban driving test is a test performed in built-up urban area where participants have to avoid accidents in six scenarios. Each scenario was elaborated using the description of the infrastructure and time positioning of the vehicles and/or pedestrians from the Detailed Accident Study data from INRETS/MA, which constitute reference situations. The situations encountered imply high order cognitive processes such as dealing with conflict situations, constant shifting attention and monitoring and evaluation of performance that contrasts with monotonous driving. As previous findings using cognitive tests different from driving tasks have shown longer reaction time in case of conflict situations (Giora et al., 2017; Perrier et al., 2015) in insomnia patients compared to good sleepers, we may expect driving impairments in insomnia patients during the urban driving test. The car-following test measures changes in controlled information processing and mainly requires maintaining an adequate vigilance level under a shorter period of time than monotonous driving and can be considered to involve lower cognitive demand than the urban test. Because we previously proposed that insomnia patients are able

to maintain an adequate level of vigilance during a short period of time, we do not expect driving impairments in insomnia patients during the car-following test.

The aim of the present study was thus to assess driving performances of insomnia patients in daily routines tasks such as urban and car following tests.

2. Methods

2.1. Participants

The data presented in this paper are part of a larger study designed to evaluate various driving performances in insomnia patients (See Perrier et al., 2014, for highway driving performance). The protocol was granted ethical approval by the Caen Northwest III ethics committee and by the Health Ministry (number DGS 2005/0388). Each participant provided written consent in accordance with the requirements of the committee. As described previously in Perrier et al., 2014, participants were recruited via announcements posted in public transportation centers, medical centers, and newspapers. Following a telephone interview, participants from both groups were carefully interviewed by a sleep clinician to ascertain: (1) sleeping difficulties and diagnosis of DSM-IV insomnia for the insomnia patients group; and (2) good physical condition: the absence of sleep, alertness, neurological, cardiovascular, respiratory, hepatic, renal, or metabolic disorders, and absence of poor hygiene or habitual abnormal sleep patterns (e.g., night or shift work) for the good sleepers group. Participants included in the insomnia group had to meet the following inclusion criteria according to DSM-V primary insomnia criteria: (1) presence of a subjective complaint of insomnia, defined as difficulty initiating (sleep onset latency (SOL), > 30 min) and/or maintaining sleep (time awake after sleep onset > 30 min); (2) early awakening (< 6.5 h of sleep or waking up earlier than the desired wake time); (1) and (2) had to occur at least 3 nights per week; (3) insomnia for at least 6 months; (4) insomnia or its perceived consequences causing marked distress or significant impairment of occupational or social function (problems of concentration); and (5) presence of a subjective complaint of at least one negative daytime consequence attributed to insomnia (e.g., fatigue, mood disturbances).The exclusion criteria were: (1) current medical or neurological disorder that could compromise sleep; (2) serious psychopathology that could induce insomnia; (3) consumption of psychotropic or other medications known to alter or induce

sleep; (4) poor hygiene or habitual abnormal sleep patterns (e.g., night or shift work); and (5) other sleep disorders (assessed by polysomnography [PSG]) such as sleep apnea (apnea-hypopnea index > 10), or periodic limb movements during sleep (myoclonic index with arousal > 10). All participants with insomnia and good sleepers were excluded if they: (1) had current or past dependence on alcohol, opiates, benzodiazepines, or any illicit drugs; (2) smoked more than five cigarettes per day; (3) drank more than 28 units of alcohol per week; or (4) consumed more than 150 mg of caffeine per day. All participants had normal or corrected to normal vision (visual acuity greater than or equal to 7/10). They had all driven regularly for at least 2 years and drove at least 5,000 km/years.

2.2. Driving tasks:

The urban and car following driving tasks were performed between 4.00 and 5.00 PM. Tasks took place with the INRETS-FAROS driving simulator, equipped with an ARCHISIM object database (Espié and Auberlet, 2007), that reproduces several aspects of a current medium-sized car (dashboard, five-speed gearbox, pedals and steering wheel). The simulator produces engines and tire-squeal sound effects that correlate with the speed of the vehicle but has no system that enables a simulation of the movements of the car. The cabin was associated with an interactive display unit which reproduced the motorway scenery with computer-generated pictures on a 1.3x1.7 meters screen located in front of the cabin at 2.3 meters from the subject. The acquisition frequency for the different signals (position, speed, acceleration, etc.) was 30 Hz.

Participants were trained with the simulator one week before the experimental day to familiarize with the urban virtual environment and detect motion sickness sensibility. During training, each participant drove to the urban circuit without occurrence of accidents scenarios and none of the participants suffered from motion sickness.

Urban test, simulated accident scenario

This test has been described in a previous article conducted in our laboratory (see Meskali et al., 2009, for details). To summarize, participants had to drive at a speed of maximum 50 km/h as in real urban driving situation, for approximatively 15 minutes, and were instructed to follow the road signs indicating down town, knowing that accidents may happen during the test. Participants were not aware of the nature

and of the moment of occurrence of the accident scenarios. . A few independent vehicles with non-conflicting behaviors were driving along the route. The accidents scenario were spatio-temporally implemented based on reference situations from the Detailed Accident Study data from IFSTTAR that provides highlight precise information related to the description of the infrastructure and time positioning of the vehicles and/or pedestrians involved in a scenario (Berthelon et al., 2008). Therefore, the urban driving test was built to reproduce a chain of events and relations of causality in the different phases leading to the collision that are known to occur frequently in an urban environment, inspired by real accidents. In addition, this task requires using cognitivo-sensori-motor resources by driving in a virtual environment while being attentive to stimuli such as pedestrians and other vehicles.

Participants had to drive in six scenarios of accident, implemented in a counterbalanced order, in an urban environment, five of them have been described in Meskali et al., (2009) : “Hidden pedestrian crossing” scenario (pedestrian); “Sudden stop of the vehicle ahead at a traffic light” scenario (traffic light); “Vehicle overtaking and merging back into the lane” scenario (vehicle overtaking); “Vehicle pulling out from a parking space” scenario (parking place); “Left-hand turn by the vehicle ahead” scenario (left-hand turn). A sixth scenario was built for this study “Vehicle suddenly entrance in petrol station”: the driver travels on a two-lane roadway, a vehicle coming in the opposite direction cuts its trajectory to reach the entrance of a petrol station.

A time breakdown was performed to specify key moments in the scenarios. Pedal signals were smoothed (order-7 mobile center algorithm) and an algorithm detected the pressing of the pedal. The following variables from the start of each scenario were calculated: 1) the response time, which was calculated starting from initiation of the first press on the brake pedals, and 2) the speed of the driver's vehicle, which was obtained by central derivation of the position in relation to time and was filtered with a Dual Butterworth order-2 filter. The main outcomes measures were the number of accidents, the response time, the speed and the standard deviation of speed at the origin of each accident scenario. In case of a lack of significant difference between insomnia patients and good sleepers for the number of accidents, the response time, the speed and the standard deviation of speed will be averaged for all accident scenarios. Especially, we will calculate the total number of accidents during the urban test per

participant and the average will constitute the mean of the total number of accidents per participant. The speed at the origin of the scenario may help to explain the behavior of the participants and the origin of the accident, if occurring. For example, a reduced speed at the origin of the scenario would suggest greater caution allowing participant to avoid putting himself under hazardous situations that would result in traffic accident. In contrast, a greater speed could suggest difficulty to react quickly and reduce speed in order to avoid the accident which would explain the occurrence of a traffic accident. Moreover, greater mean speed has been observed after hypnotics use (see Meskali et al., 2009) which has been interpreted as greater disinhibition, a dangerous behavior during driving.

Car following test

The car following test involved driving for 15 minutes behind a car which accelerated, decelerated (+/- 10 or 20 km/h) and adopted three speeds (70, 80 or 90 km/h) during 20, 30 or 40 s. Each speed change was separated from another by a period of stable speed. Participants were instructed to maintain a safe distance between this car and their own vehicle. They had to drive as much as possible in the center of the right lane. The driving task used for this study was a monotonous road, yet it was realistic in order to maintain ecological validity. After completion of the driving tests, we calculated two main parameters, the intervehicular distance and the standard deviation of the lateral position. The intervehicular distance (m) was measured from the rear of the lead vehicle to the bumper of the subject vehicle (Green, 2013). This parameter reflects the ability of maintaining safe distance with the lead vehicle and can thus characterize driver's control. The standard deviation of the lateral position (cm) was calculated according to the mathematical definition described in Verster and Roth (2011), larger values indicate poorer lane-keeping performance with higher risks of lane departure and collisions with other vehicles (McLaughlin et al., 2009). Recent studies have shown that both parameters were sensitive to reveal poorer performance of a driver engaged in phone conversation when followed a preceding vehicle (He et al., 2014; Saifuzzaman et al., 2015).

2.3. Statistical Analyses

Statistical analyses were performed with STATISTICA Version 13 (StatSoft®). For comparisons of the two unpaired groups, for non-Gaussian samples, preference was given to the Wilcoxon-Mann-Whitney test. Significance level was set at the $p < 0.05$ level.

2.4. Missing data

Over the 21 insomnia patients that were included in the study, data collected during the car following and the urban driving tests were unavailable for 5 participants for the car following test and for 1 participant for the urban driving due to technical problem (unexpected stopping of the driving simulator). Therefore, the data obtained from the same 15 patients with primary insomnia (5 men and 10 women; mean age=46±14 years; age range=25-65 years) and 16 good sleepers were analyzed and presented in the current paper (6 men and 10 women; mean age=48±14 years; median=50 years, age range=23-64 years).

3. Results

Demographic description of the population

Results are described in Table 1. Both insomnia patients and good sleepers differed in terms of subjective sleep quality according to results of the ISI and the PSQI. None of other demographic variables differed between groups.

Table 1: Demographic characteristics of both insomnia patients and good sleepers.

Demographic parameters	**Insomnia patients n = 15 Mean (SD)**	**Good sleepers n = 16 Mean (SD)**	***U* values**	***p* values**
ISI	14.80 (2.77)	2.55 (1.63)	*0*	*<.001*
PSQI	9.75 (1.75)	4 (2.07)	*2.5*	*<.001*
Horne and Ostberg	58.65 (6.70)	60.33 (8.70)	*64*	*0.57*
Epworth	7.78 (5.21)	6.2 (3.88)	*53*	*0.41*
Driving licence (date of obtention)	1978 (14)	1983 (13)	*49*	*0.48*
Number of accidents	0.69 (0.75)	0.92 (0.95)	*74*	*0.61*
Age	51.63 (16.60)	48.31 (14.22)	*78*	*0.64*
Sex (F/M)	10/5	10/6	*NA*	*NA*
Education level (years)	8.80 (3.91)	9.31 (2.63)	64	0.98

For comparisons of two (unpaired) and non-Gaussian groups, preference was given to the Wilcoxon-Mann-Whitney test.
F, Female; M, Male; ISI, Insomnia Severity Index; PSQI, Pittburg Sleep Quality Index.

Urban driving test

Table 2: Urban driving test. Driving parameters were obtained at the start of the scenarios as a function of groups and were then averaged for all accident scenarios.

Driving parameters	**Insomnia patients n = 15 Mean (SD)**	**Good sleepers n = 16 Mean (SD)**	***U* values**	***p* values**
Average of the total number of accidents	3 (0.41)	4 (0.58)	120	1
Average of the response time for all accident scenarios) (seconds)	2.42 (0.81)	2.33 (0.46)	111.5	0.74
Averaged speed over all accident scenarios) (km/h)	37.17 (6.58)	39.14 (5.23)	99.5	0.42
Averaged standard deviation of speed over all accident scenarios) (km/h)	11.38 (5.27)	11.16 (5.41)	117	0.92

For comparisons of two (unpaired) and non-Gaussian groups, preference was given to the Wilcoxon-Mann-Whitney test. SD, Standard deviation; km, kilometers; h, hours. Each participant can cause between 0 and 6 traffic accidents during the urban test. We calculated the total number of accidents per participant and the average constitutes the mean of the total number of accidents per participant.

None of the variables revealed significant differences between groups.

Car Following test

Table 3: Car following test. Driving parameters obtained as a function of groups.

Driving parameters	**Insomnia patients n = 15 Mean (SD)**	**Good sleepers n = 16 Mean (SD)**	***U* values**	***p* values**
Intervehicular distance (m)	67.32 (8.58)	66.66 (5.07)	116	0.89
Standard deviation of lateral position (cm)	18.2 (6.7)	18.5 (7.3)	113	0.80

For comparisons of two (unpaired) and non-Gaussian groups, preference was given to the Wilcoxon-Mann-Whitney test.
SD, Standard deviations; m, meters; cm, centimeters.

None of the variables revealed significant differences between groups.

4. Discussion

The aim of the present study was to assess driving performances of insomnia patients in urban and car following conditions frequently encountered in daily life driving situations. Our results did not reveal any behavioral difference in both driving tests between insomnia patients and good sleepers.

This study is, to our knowledge, the first report related to performances of insomnia patients in a simulated driving urban test, in which prototypical accident scenarios were introduced, reproducing the space–time features of accident-causing situations. These situations have been developed since 10 years ago based on detailed analyses of real driving accidents and the reproduction of these situations of accidents in virtual environment. However, the urban driving test is, to date, rarely used. The major interest of this virtual environment test is related to the possibility to introduce the scenarios at specific moment during the test in order to reliably create situations of traffic accidents. In contrast, on-the-road driving does not allow having control over the accident scenarios and their occurrence. Owing to the lack of similar studies using the urban driving test in various populations and none with insomnia patients, it is difficult to establish comparisons with our results.

Nevertheless, due to the nature of the urban driving test, we can compare our results with previous ones obtained using complex reaction time task requiring high-order cognitive processes. Indeed, during the urban test, participants are required to generate the appropriate answer as quickly as possible by analyzing risky situations for pedestrians or other cars. This test is thus considered to involve high-order cognitive processes such as inhibition, flexibility and is highly stimulating. Although recent studies showed longer reactions times in insomnia patients compared to good sleepers in case of conflict situations (Giora et al., 2017; Perrier et al., 2015), the present study did not revealed driving behavior impairment in situations involving in part these processes. Even if we cannot exclude a lack of sensitivity of the scenarios used to detect behavior impairments, there is no proof of it in view of previous driving impairments detected using these scenarios following acute zolpidem administration (Meskali et al., 2009). A more likely explanation would be, that, during urban driving, insomnia patients may have developed compensatory mechanisms to perform the task correctly that was not the case during

monotonous driving (Perrier et al., 2014). Indeed, we supposed that both tests involve higher levels of stimulations and of actions than monotonous driving, insomnia patients were probably able to maintain a sufficient alert state for a short period of time.

Our study did not reveal any behavioural impairment on the major parameters (intervehicular distance, SDLP) of the car following test in insomnia patients Our results are in line with those of Leufkens and colleagues' study (Leufkens et al., 2014), in which insomnia patients were all under medication and drove under real driving conditions, using the standardized methodology assessing SDLP (Verster and Roth, 2011). Altogether, these findings tend to indicate that insomnia patients do not have a dangerous behavior under such driving conditions, both simulated and real. However, due to previous discrepant results between simulated and real driving's study on monotonous driving, caution is needed before generalization of our results. Further studies are needed using on-the-road driving tests with untreated insomniacs as already suggested in editorial's paper of Verster and Roth (2014). Nonetheless, our result indicates that insomnia patients are able to keep their vehicle stable and adjust it with the flow of traffic. As for the urban driving test, we suppose that the lack of impairment during the car-following test would be linked to the higher interest and effort needed to perform it, at it is more complex and less boring than the monotonous driving test. Indeed, divergent results between monotonous driving and car-following test have been previously found (e.g. Bosker et al., 2012; Schumacher et al., 2017) and have been interpreted in terms of greater sensitivity of the monotonous driving test compared to the car following to sleep modifications and sedative drugs effects. To confirm this hypothesis, it would be interesting to increase the duration of the car following test to perhaps observe driving impairments after a longer period of time.

Altogether, our results revealed that insomnia patients had no behavioral impairment during daily routines driving tasks of short period of time (i.e. less than 15 minutes) which is a positive message for the patients. Although the simulator environment is known to lead to larger SDLP values than the on-the-road driving test (Helland et al., 2013; Verster and Roth, 2014), in the current study, the virtual environment did not increased the risk taking and the levels of sleepiness as we did not observe more accidents or larger SDLP in insomnia patients compared to good sleepers. Indeed, virtual environment

is one possible explanation of the impaired driving performance observed in Perrier 2014's study that would have facilitated the detection of impaired driving performance. However, our findings need to be confirmed as a possible explanation of the lack of driving impairments may be the time of day for completion of the driving tests. Indeed, previous reports have demonstrated circadian desynchrony in insomnia patients in lights of core body temperature, urine melatonin and metabolites profiles (Gehrman et al., 2018; Lack et al., 1996; Morris et al., 1990). Altogether, their results suggest a delay in the timing of the wake maintenance zone in insomnia patients (See Lack et al., 2008, for review) that may probably impact the discrepant cognitive performances observed that were evaluated at different times as proposed previously (Shekleton et al., 2010). Therefore, investigating driving performances under urban and car following conditions at different times of the day may underline potential time of day variations in insomnia patient's performances. In order to supplement such investigation, it may be useful to investigate whether performances of insomnia patients are dependent of compensatory strategies partly mediated by metabolic or hormonal markers such as cortisol.

In conclusion, this study using a virtual driving environment reveals that insomnia patients have no impairment in behavior implicated in daily contexts driving tasks of short period of time performed in the late afternoon. Although our results provide a first step toward knowledge of behavioral performance during daily routine driving tasks in insomnia patients, future studies using on-the-road driving tests and different population of insomnia patients (under medication, younger versus older…) are needed. Future studies should also consider reports in line with circadian desynchrony in insomnia patients.

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